Resistivity Scaling of $CuAl2\text{-}x$ Nanowires for Post-Cu Interconnects

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Abstract:

The dimensions of copper interconnects in current microelectronic integrated circuits have decreased below copper's electron mean free path (40 nm), leading to high resistivity and thus detrimental increases in power dissipation and signal delays. To continue the downscaling of electronics while maintaining performance, a material with better resistivity is needed to replace copper in interconnects. CuAl2 is a promising candidate due to its low bulk resistivity (6.5 μΩ·cm),1 small mean free path (14 nm),1 and high electromigration resistance compared to copper.2 CuAl2 has demonstrated promising resistivity scaling in thin films,3 however, the scaling behavior of nanowires has not been studied. We report the resistivity of core-shell CuAl2-x nanowires with diameters ranging from 30 nm to 70 nm. The CuAl2-x nanowires are fabricated using thermomechanical nanomolding and possess a 5 – 10 nm thick CuAl shell with a CuAl2 core. At diameters below 45 nm, the resistivities range between 20 - 35 μΩ·cm while larger diameter nanowires show slightly higher resistivities. This scaling behavior along with improved electromigration resistance suggest that CuAl2 may be a promising post copper interconnect candidate.

Summary of Research:

We fabricated four-point probe devices on SiO2/Si substrates using the molded CuAl2-x nanowires as shown by the schematic in Figure 1a. Figure 1b shows a high angle annular dark field scanning transmission electron microscopy (HAADF-STEM) image of a nanowire device cross-section. There is a distinct contrast between the nanowire perimeter and core, revealing that the nanowires have a core-shell structure. STEM electron energy loss spectroscopy (EELS) composition mapping shown in Figure 1c shows that the core is CuAl2 while the shell is CuAl. Resistivity measurements are carried out in a cryogenic probe station at 10-6 mbar after annealing the devices at 400 K for 1 hour. A 4-point I-V curve is shown in Figure 2a, and size-dependent resistivity data for 10 nanowire devices is summarized in Figure 2b. The majority of the resistivity values of the CuAl2-x nanowires are much higher than that of bulk CuAl2 and effective Cu. Possible causes of the increased resistivity include surface roughness and compositional variations in the nanowires.

Conclusions and Future Steps:

We present the size-dependent resistivity scaling of core-shell CuAl2-x nanowires fabricated using thermomechanical nanomolding. The resistivity values are higher than that of bulk CuAl2 as well as effective Cu at comparable dimensions, possibly due to surface roughness as well as compositional variation throughout the nanowires that can increase scattering. Without these defects, it is possible that the resistivity and line resistance of stoichiometric CuAl2 nanowires could become competitive against effective Cu at nanoscale dimensions.

References:

[1] J. Appl. Phys. 136, 171101 (2024)

[2] J. Alloys and Compounds, 918, 165615 (2022).

[3] J. Vac. Sci. Technol. B 37, 031215 (2019).

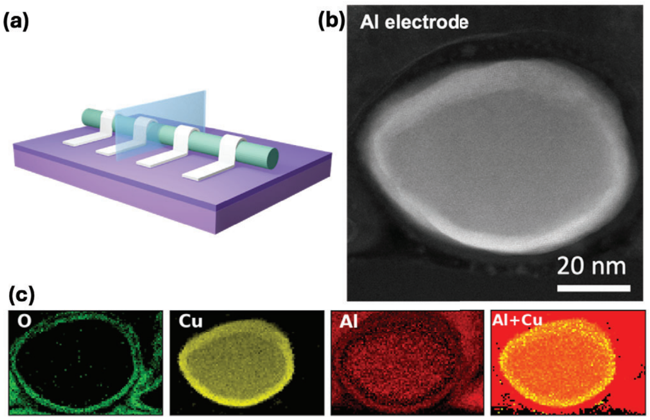

Figure 1. Cross-section analysis of core-shell CuAl2-x nanowire device. (a) Schematic showing CuAl2-x nanowire (teal) on SiO2/Si substrate (purple) with Al contacts (white). The blue plane denotes the cross-section plane of the STEM analysis. (b) HAADF-STEM image of the crosssection of CuAl2-x nanowire device. (c) STEM-EELS maps of cross-section showing O, Cu, Al, and Al and Cu elemental fractions.

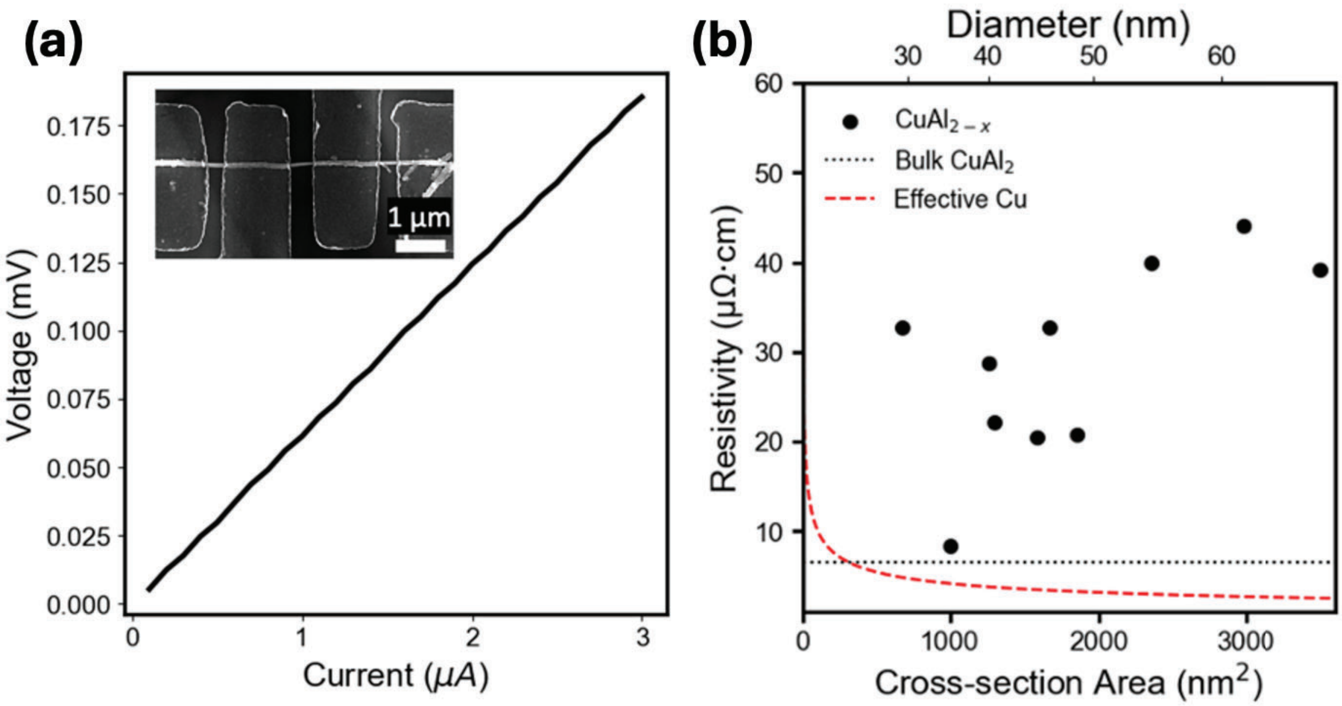

Figure 2. Transport data for CuAl2-x nanowire devices. (a) Four-point I-V curve of a CuAl2-x nanowire device. The inset shows an SEM image of the device. (b) Resistivity vs. size for ten CuAl2-x nanowire devices compared with bulk CuAl2 and effective Cu. The total core-shell cross-section area is used to calculate resistivity values.